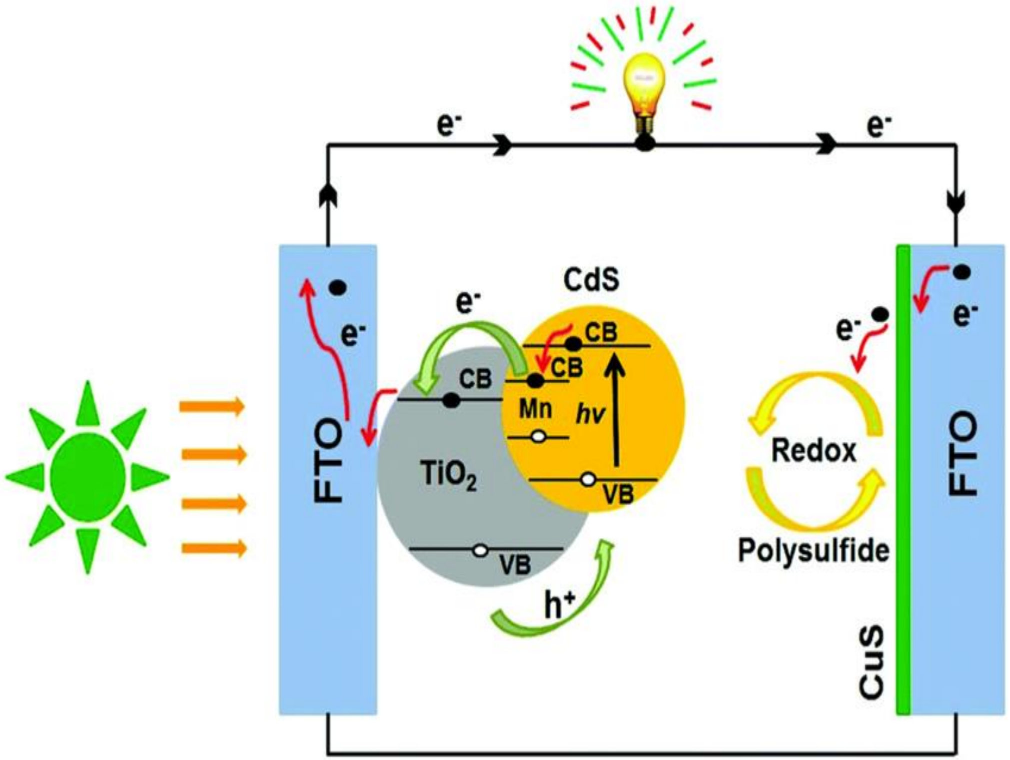
Western Norway
University of
Applied Sciences

New generation of solar cell technologies

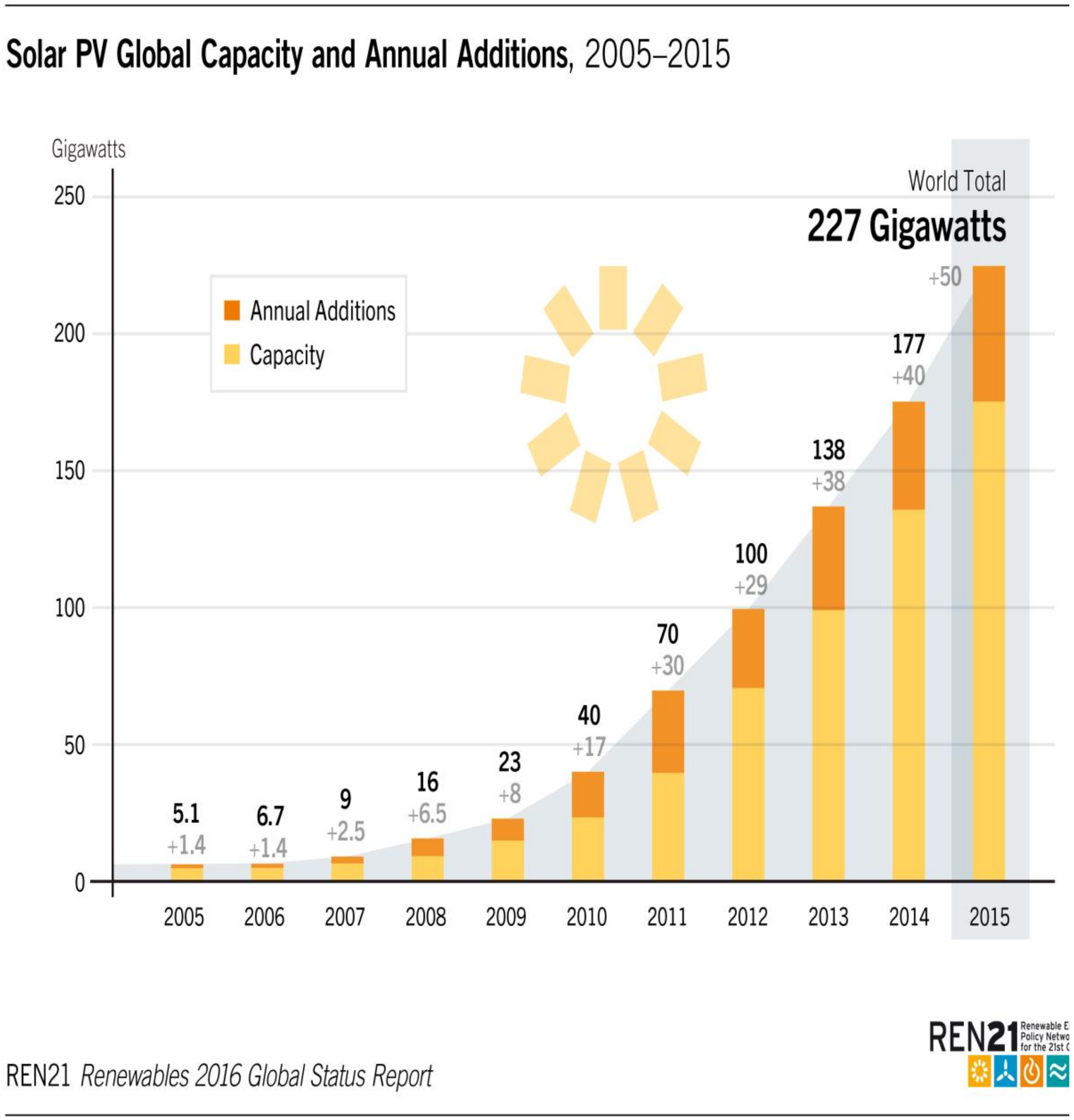
Emerging technologies and their impact on the society

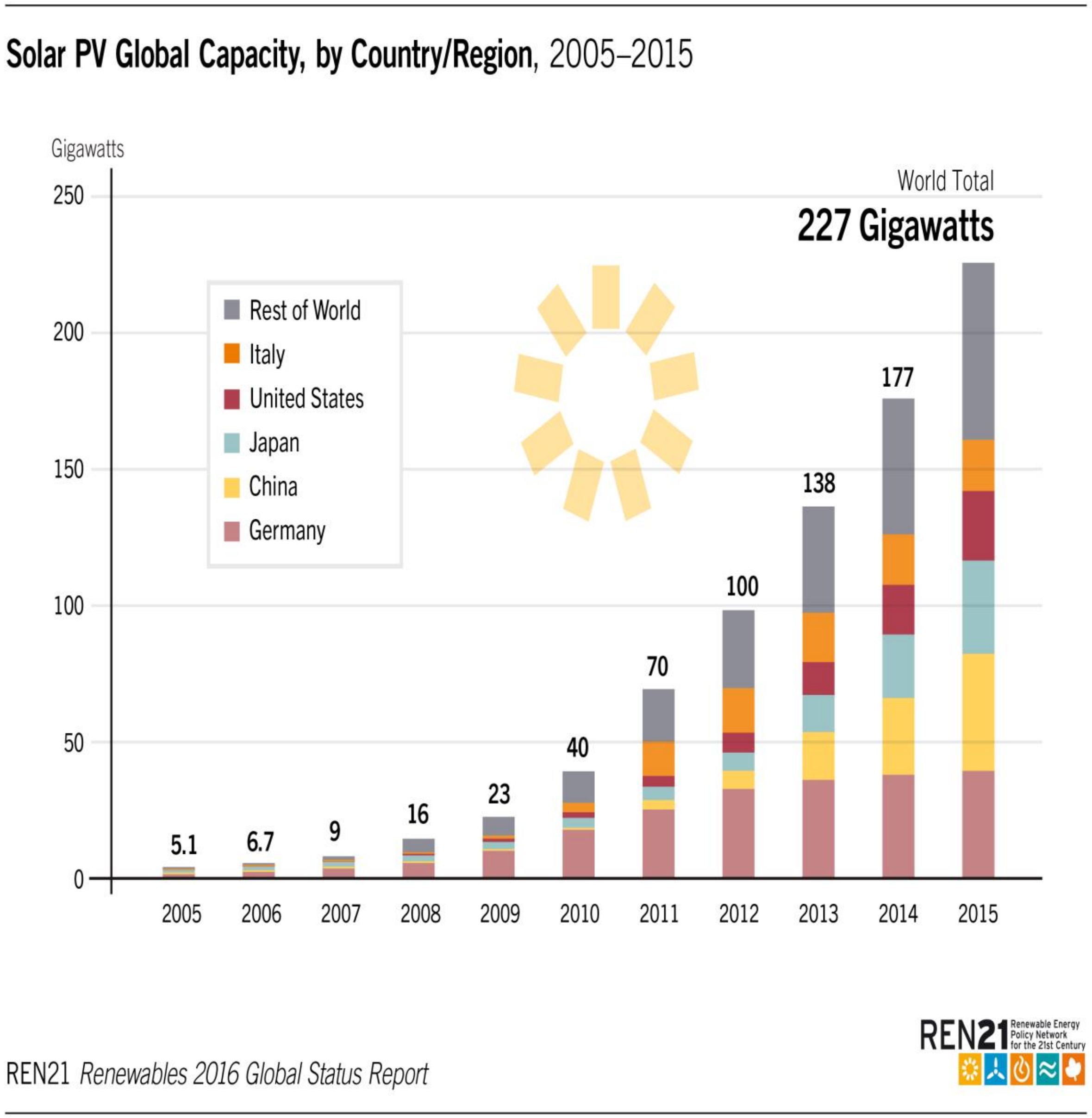
9th March 2017



Dhayalan Velauthapillai
Professor, Faculty of Engineering and Business Administration
Campus Bergen

Solar Power Capacity





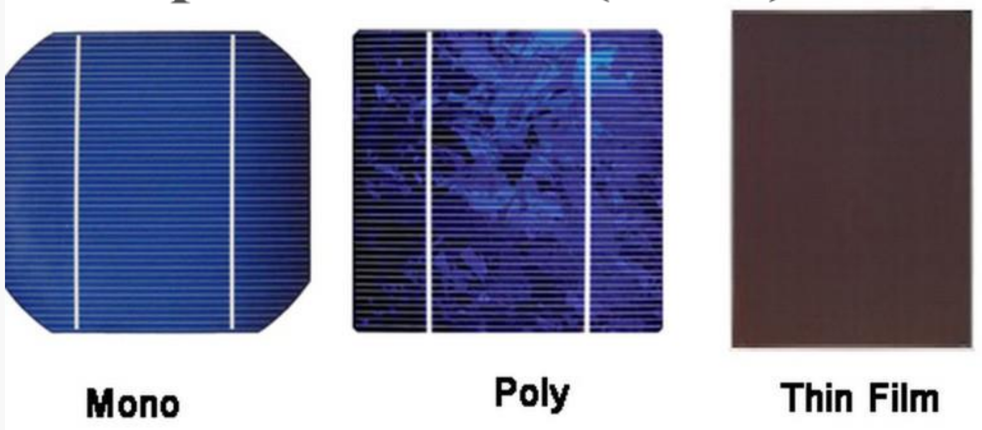
DIFFERENT GENERATION OF SOLAR CELLS

- First generation solar cells

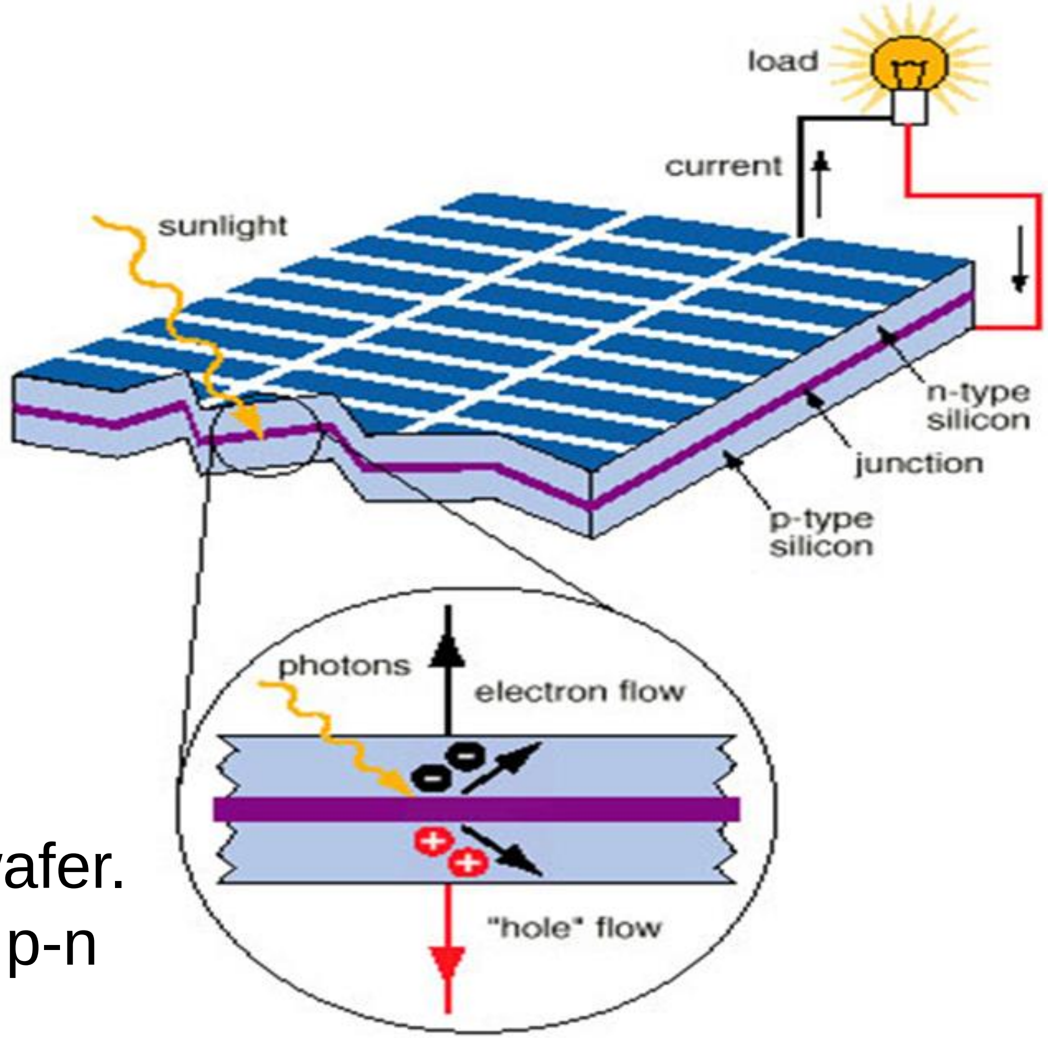
Single crystalline silicon (28 %)

Multicrystalline silicon (21%)

Amorphous silicon (16 %)



- 86% of the solar cell market
- Cells made using crystalline silicon wafer.
- Consists of a large-area, single layer p-n junction diode.



Advantages/Disadvantages of Silicon

ADVANTAGES

- Second most abundant element in the crust
- Well-developed processing techniques
- Huge market for crystalline Si
- Highest efficiency

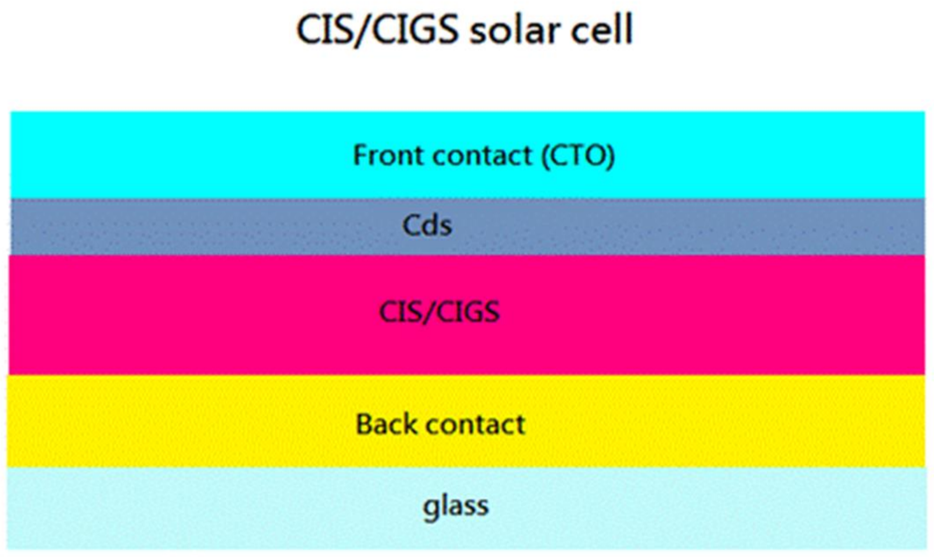
DISADVANTAGES

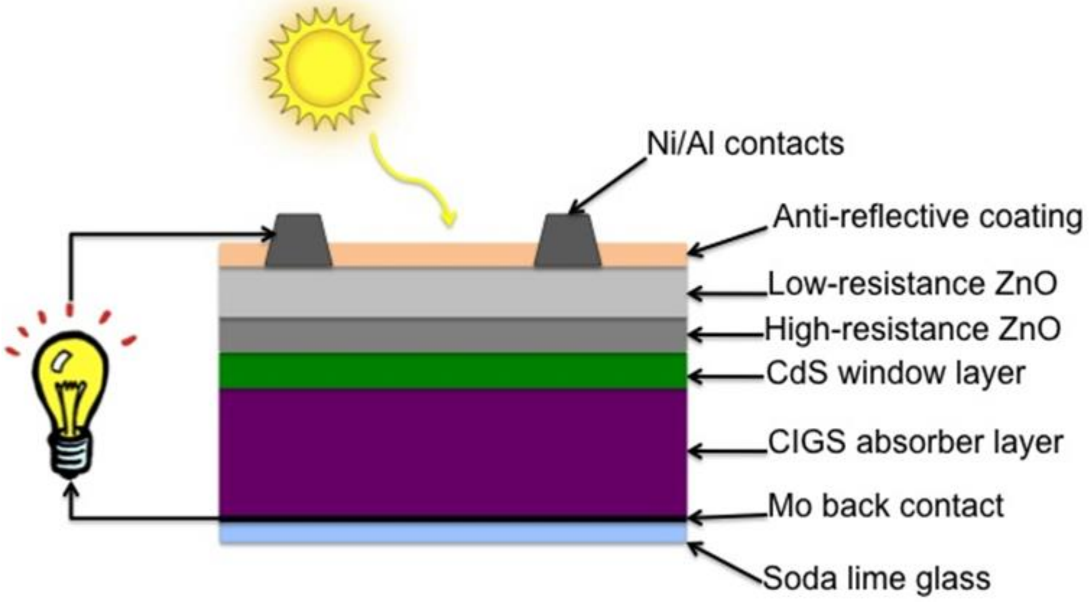
- Need thick layer (crystalline)
- Brittle
- Limited substrates
- Expensive single crystals
- Wastes during processing

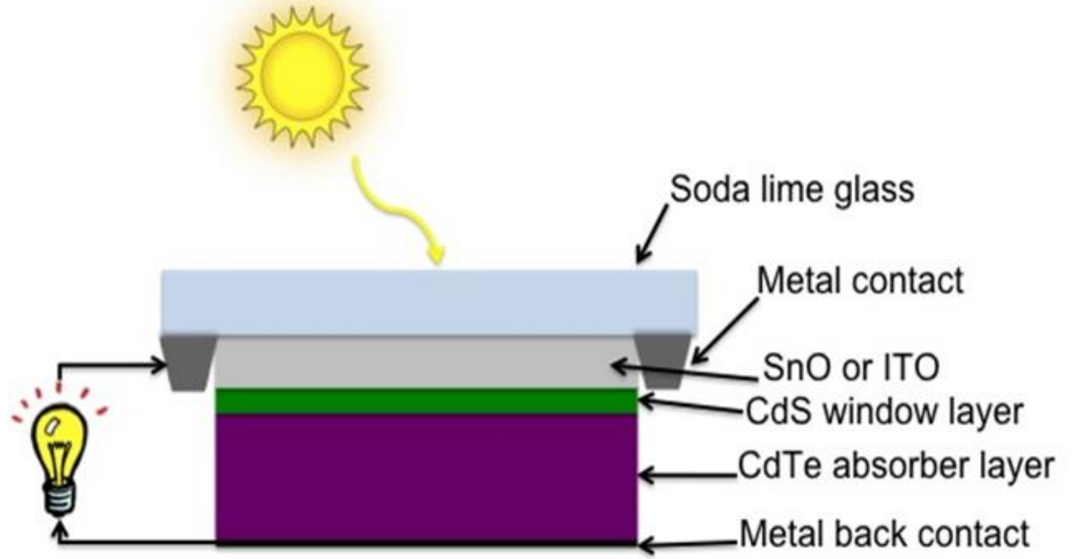
Second generation – Thin film solar cells

Copper indium gallium diselenide (CIGS) (20 %)

Cadmium Telluride (CdTe) (17 %)







Emerging solar cell technologies

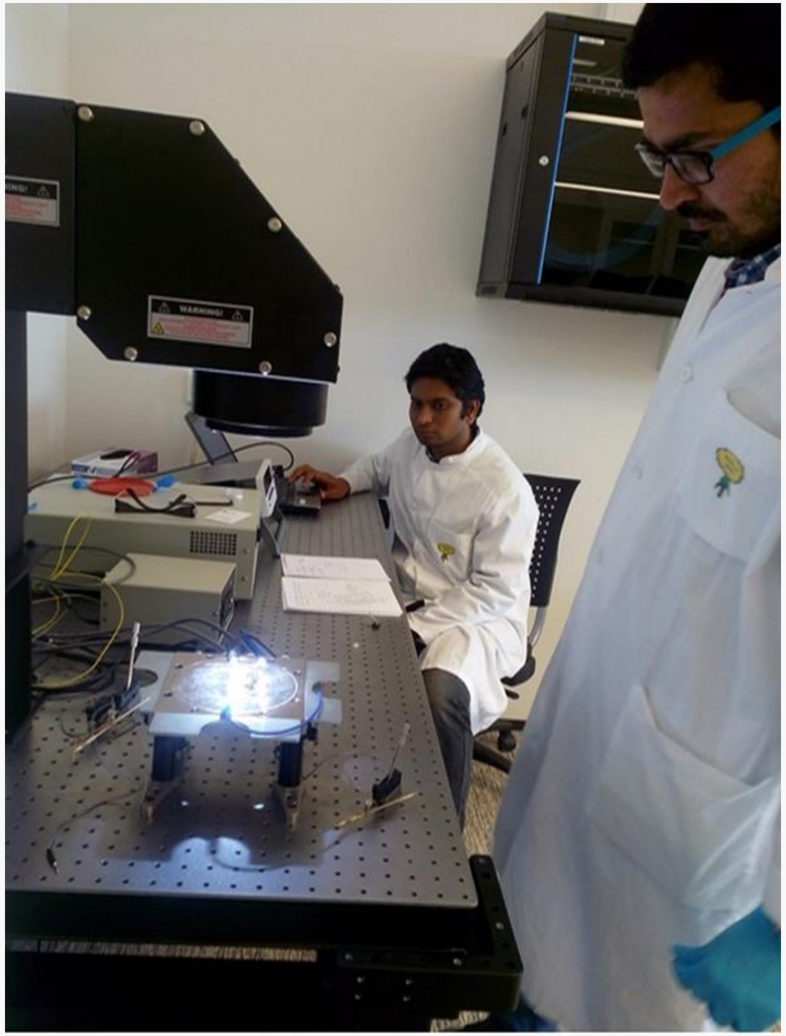
- Dye sensitized Solar Cells (DSSCs)
- Quantum Dots Sensitized Solar cells (QDSScs)
- Polymer Solar Cells
- CZTS based thinfilm solar cells
- Perovskite Solar Cells
- Intermediate band solar cells

Advanced Nanomaterials Research at HVL

A. Computer simulation studies on nanomaterials for clean energy applications

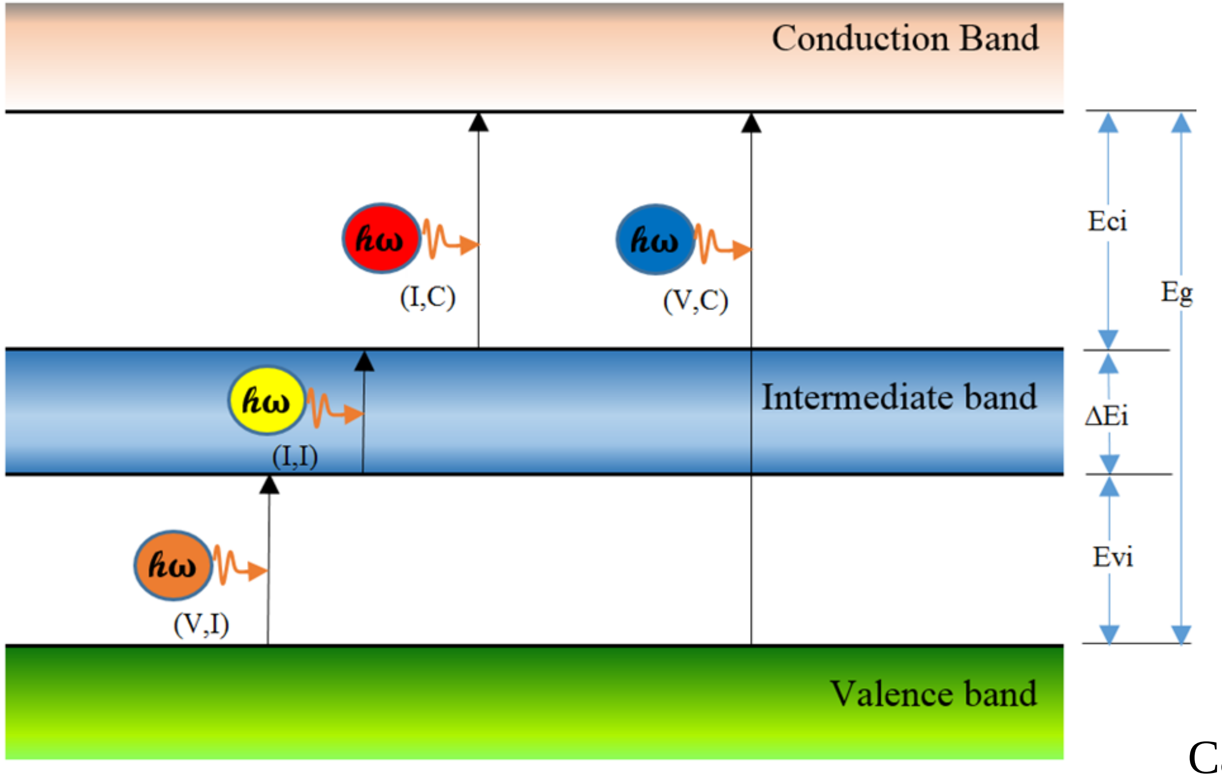
B. Synthesis, characterization studies of nanomaterials

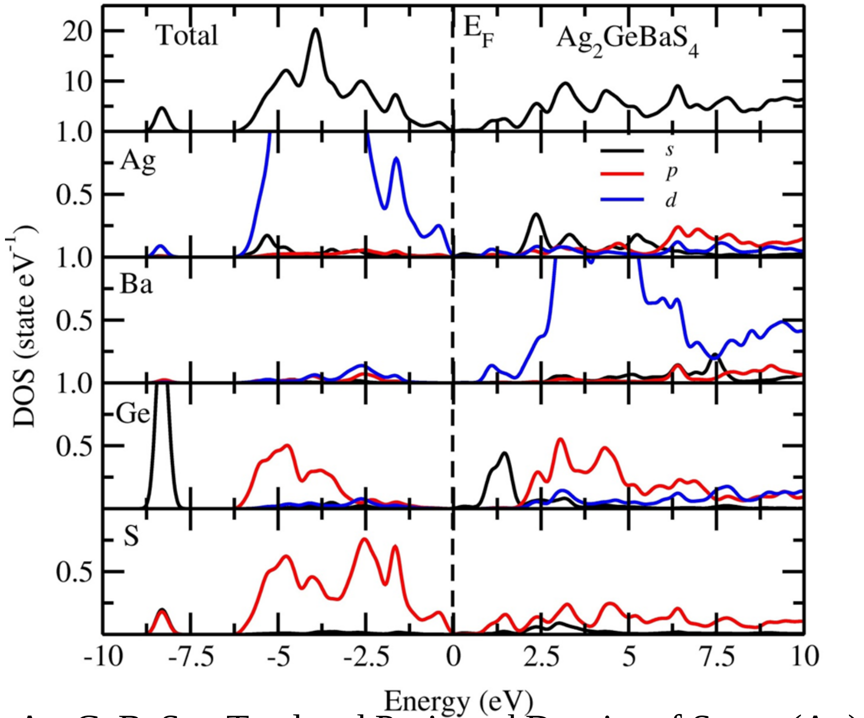
C. Fabrication and characterization of next generation solar cells



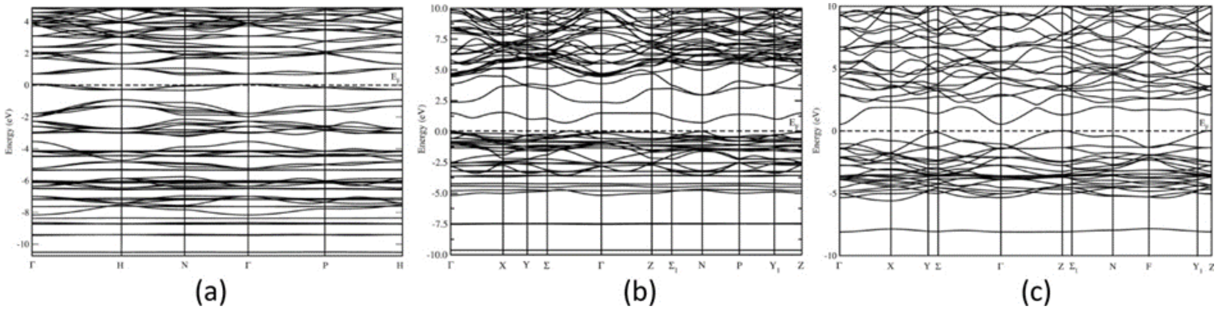
A. Computer simulation studies

- **Nanomaterials for Intermediate band solar cells**





Ag_2GeBaS_4 – Total and Projected Density of States (Ag)

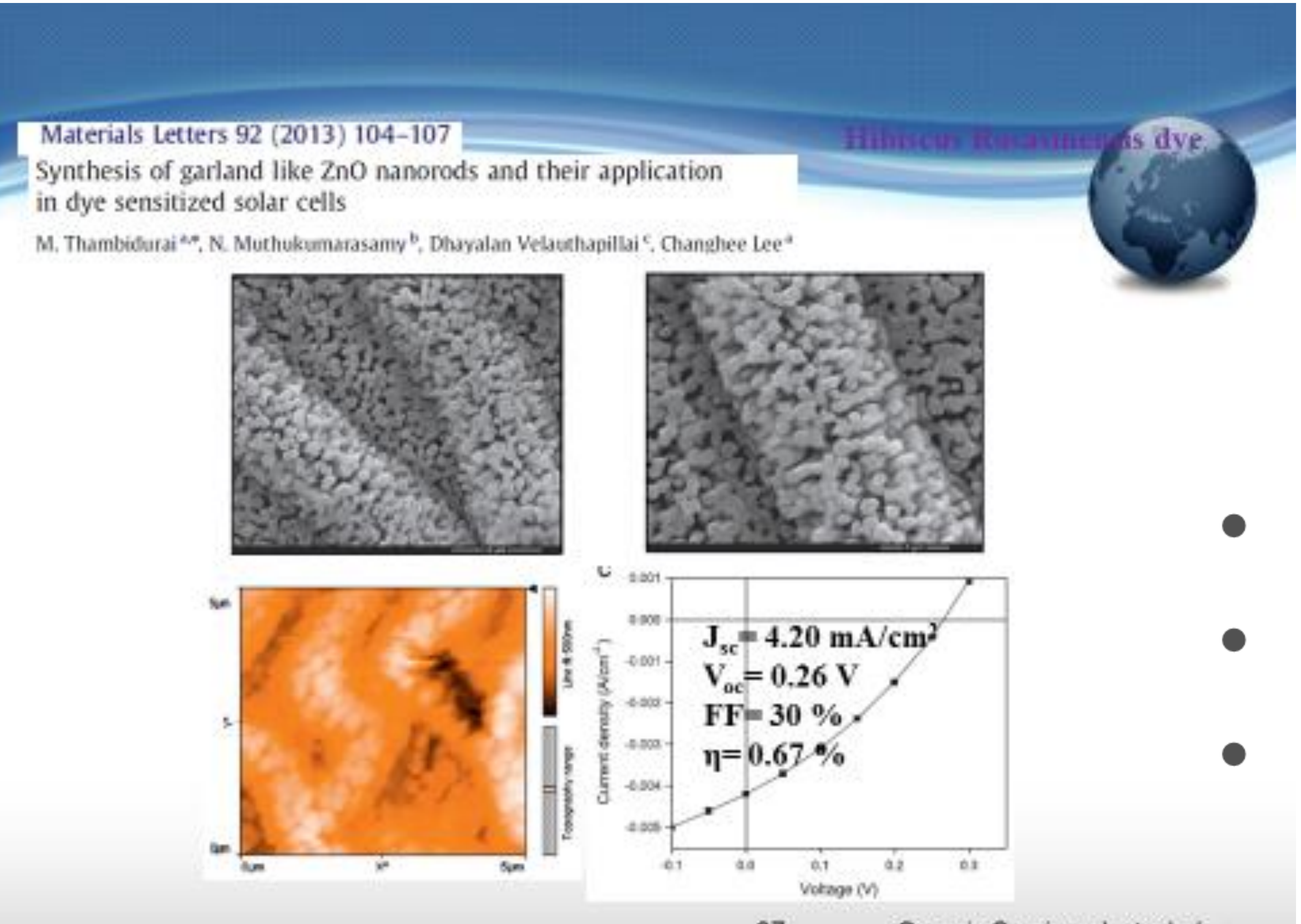


Calculated electronic band structure of (a) K_6C_{60}, (b) $Au_2Cs_2I_6$, (c) and $Ag_2GeBaS_{4.}$ The Fermi level is set to zero.

Advanced Nanomaterials Research

B. Synthesis and characterization

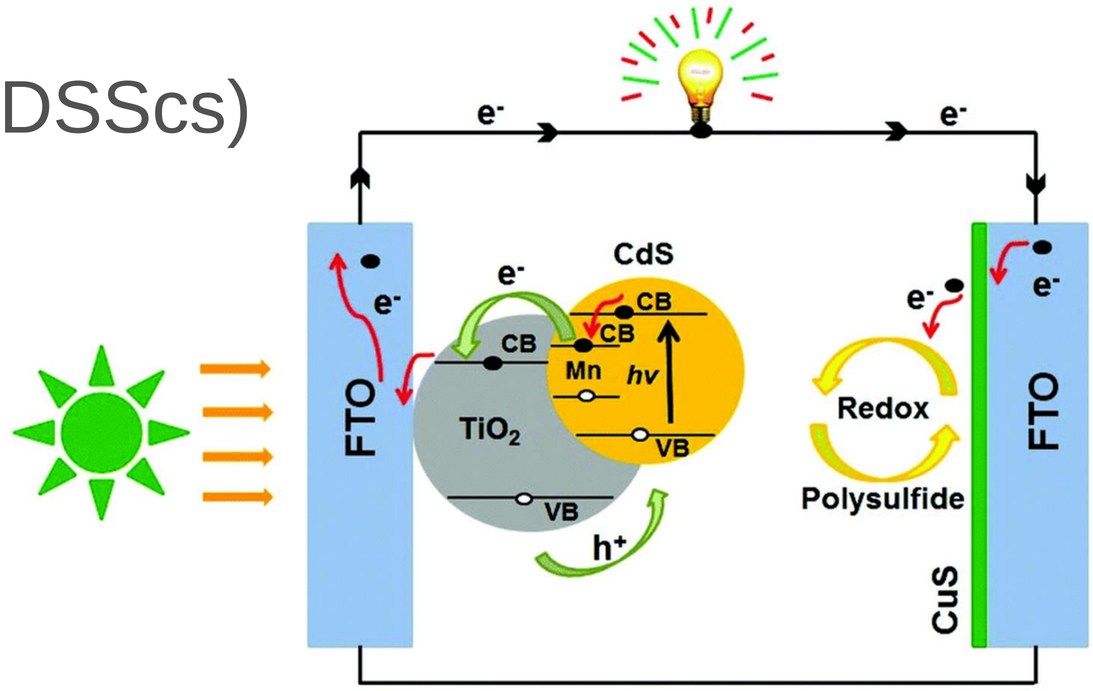
- ZnO based nanostructures
- TiO_2 based nanostructures



- CdS, CdSe quantum Dots
- CZTS thinfilm structures
- $CH_3NH_3PbI_3$ (Perovskites)

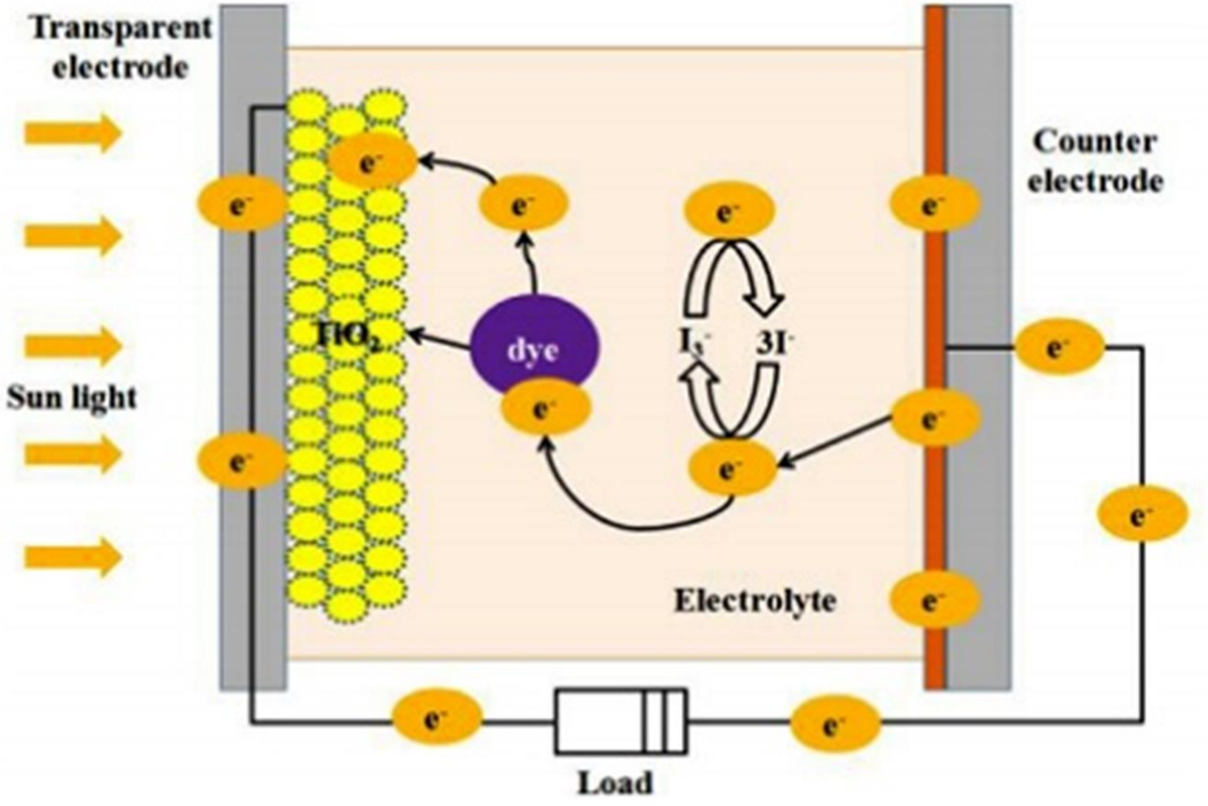
C. Fabrication and characterization of next generation solar cells

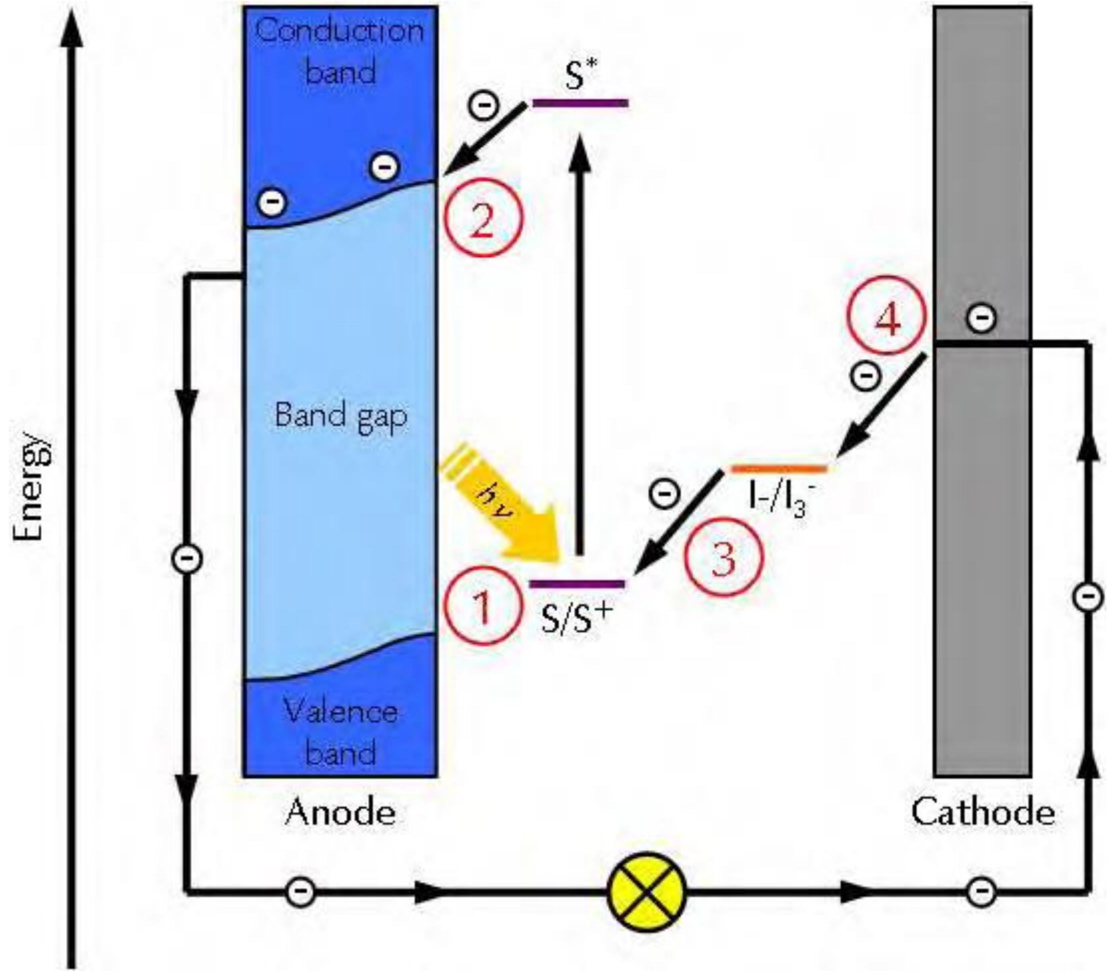
- Dye sensitized Solar Cells (DSSCs)
- Quantum Dots Sensitized Solar cells (QDSScs)
- Polymer Solar Cells
- CZTS based thinfilm solar cells
- Perovskite Solar Cells



QDSSC

Dye Sensitized Solar Cells (DSSCs)





Dye Sensitized Solar Cells

Maximum certified efficiency: 11.9%
Commercial status: advanced demonstration, some products for sale

Thanks: GCELL

Michael Grätzel holding one of his dye-sensitized solar cells

Credit: EPFL

The colors of the SwissTech Convention Center come from dye-sensitized solar cells integrated into the facade in panels made by Solaronix.

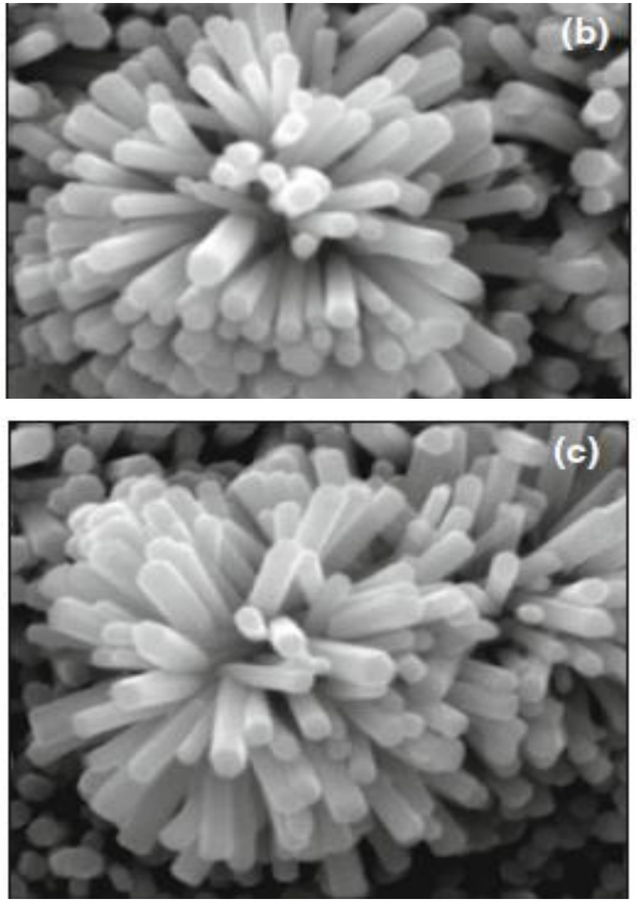
Credit: Solaronix

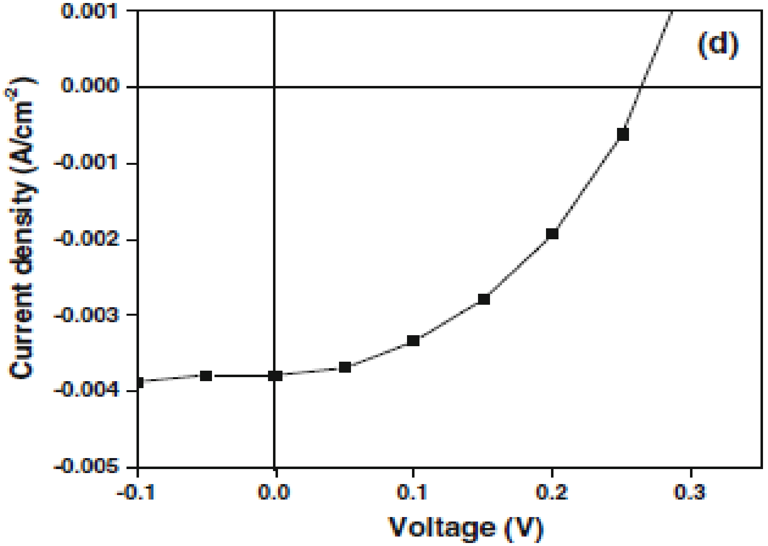
J Mater Sci: Mater Electron (2013) 24:2367–2371
DOI 10.1007/s10854-013-1103-8

Synthesis and characterization of flower like ZnO nanorods for dye-sensitized solar cells

Daucus Carota dye

M. Thambidurai · N. Muthukumarasamy ·
Dhayalan Velauthapillai · Changhee Lee

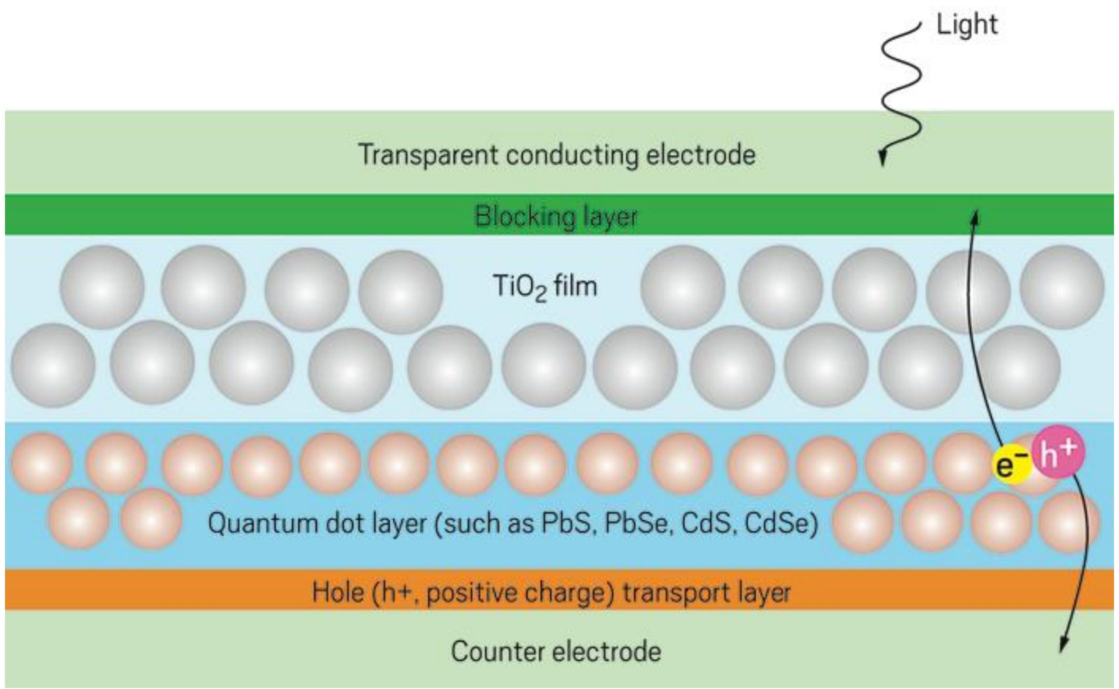




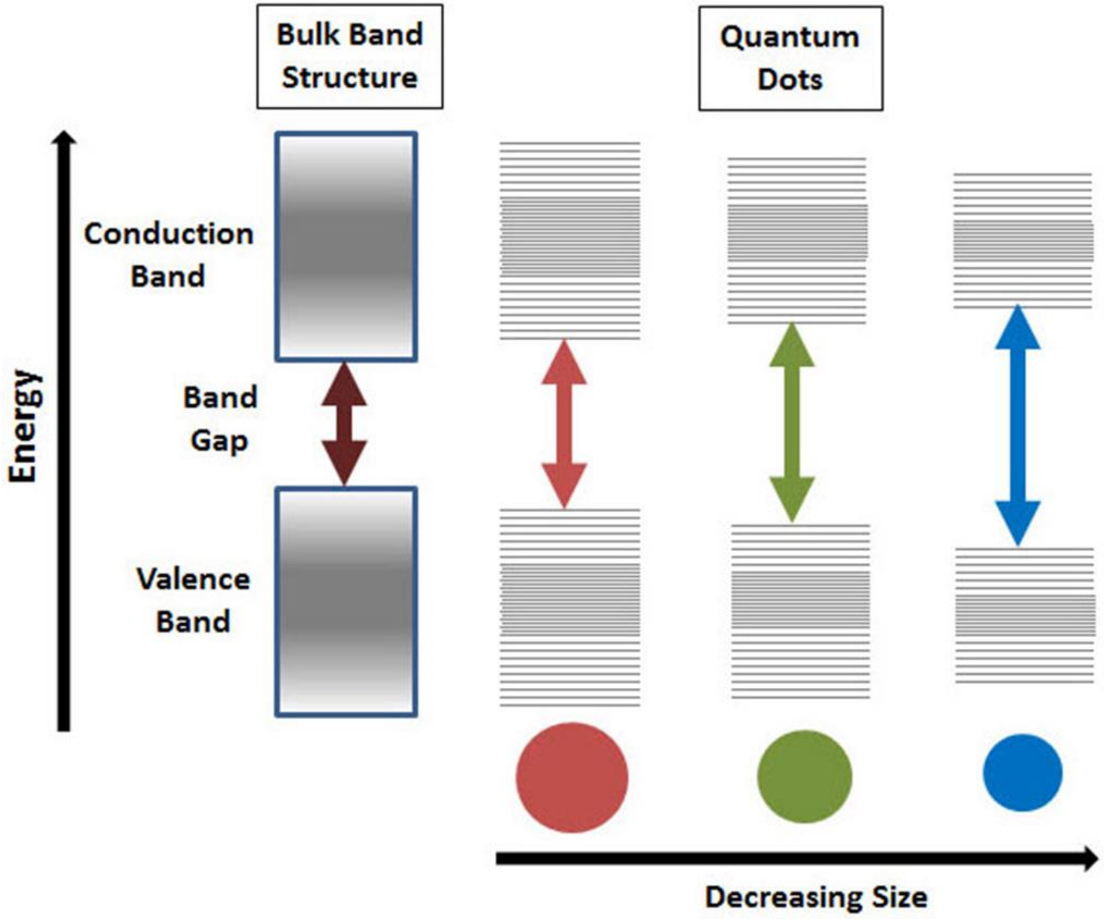
J_{sc}= 3.70 mA/cm^2
V_{oc}= 0.26 V
FF= 39 %
η= 0.78 %

Quantum Dot Sensitized Solar Cells

Maximum certified efficiency: 11.3%
Commercial status: development, no products



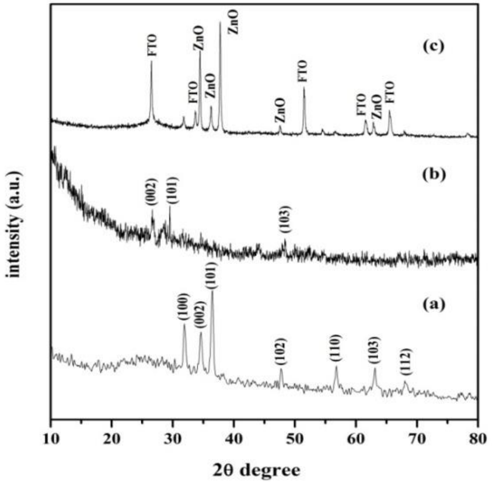
Credit: Adapted from J. Phys. Chem. Lett.



Source: Sigma-Aldrich

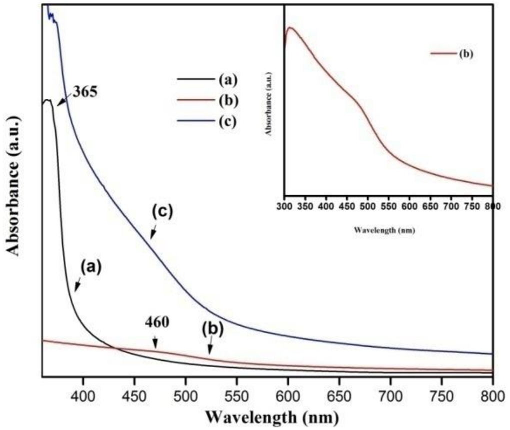
CdS Quantum dots Sensidized Solar Cells

X-ray diffraction studies

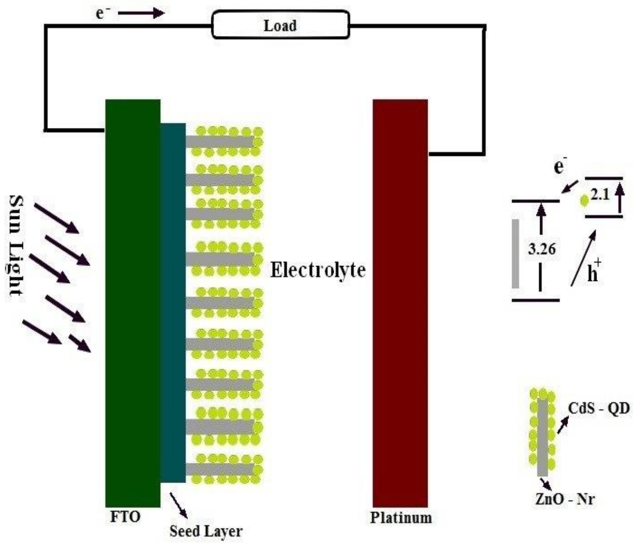


X-ray diffraction pattern of (a) ZnO NRs, (b) CdS QD and (c) CdS QD sensitized ZnO NRs based thin film

UV analysis

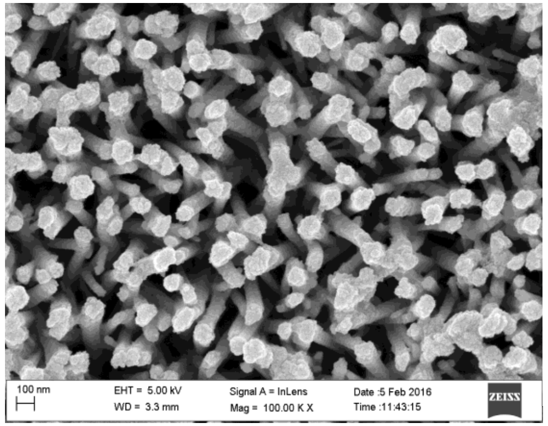


Absorption spectra of (a) ZnO nanorods, (b) CdS Quantum dot and (c) CdS QD sensitisized ZnO nanorods thin film



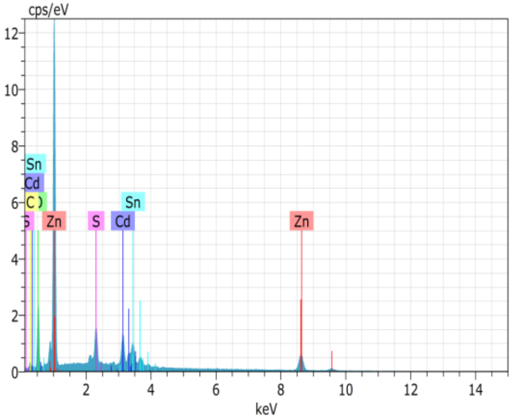
The schematic diagram of the fabricated solar cell

FESEM analysis



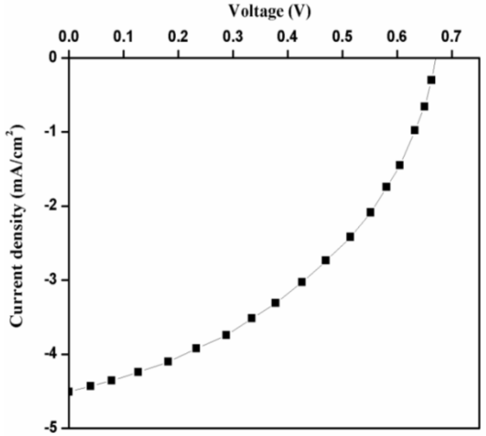
FESEM image of prepared CdS QD sensitized ZnO nanorods

EDAX analysis



EDAX spectra of CdS QD sensitized ZnO nanorods

J-V Characteristics



J-V characteristics of CdS quantum dot sensitized ZnO nanorods based solar cells

V_{oc} = 0.67 V
Jsc = 4.5 mA cm^{-1}
FF = 0.43

The constructed solar cell exhibited an efficiency 1.3%

D. Vinoth Pandi, et al., The performance of CdS quantum dot sensitized ZnO nanorod-based solar cell. Journal of Sol-Gel Science and Technology: p. 1-6.

CdS qunatum dot sensitized solar cells

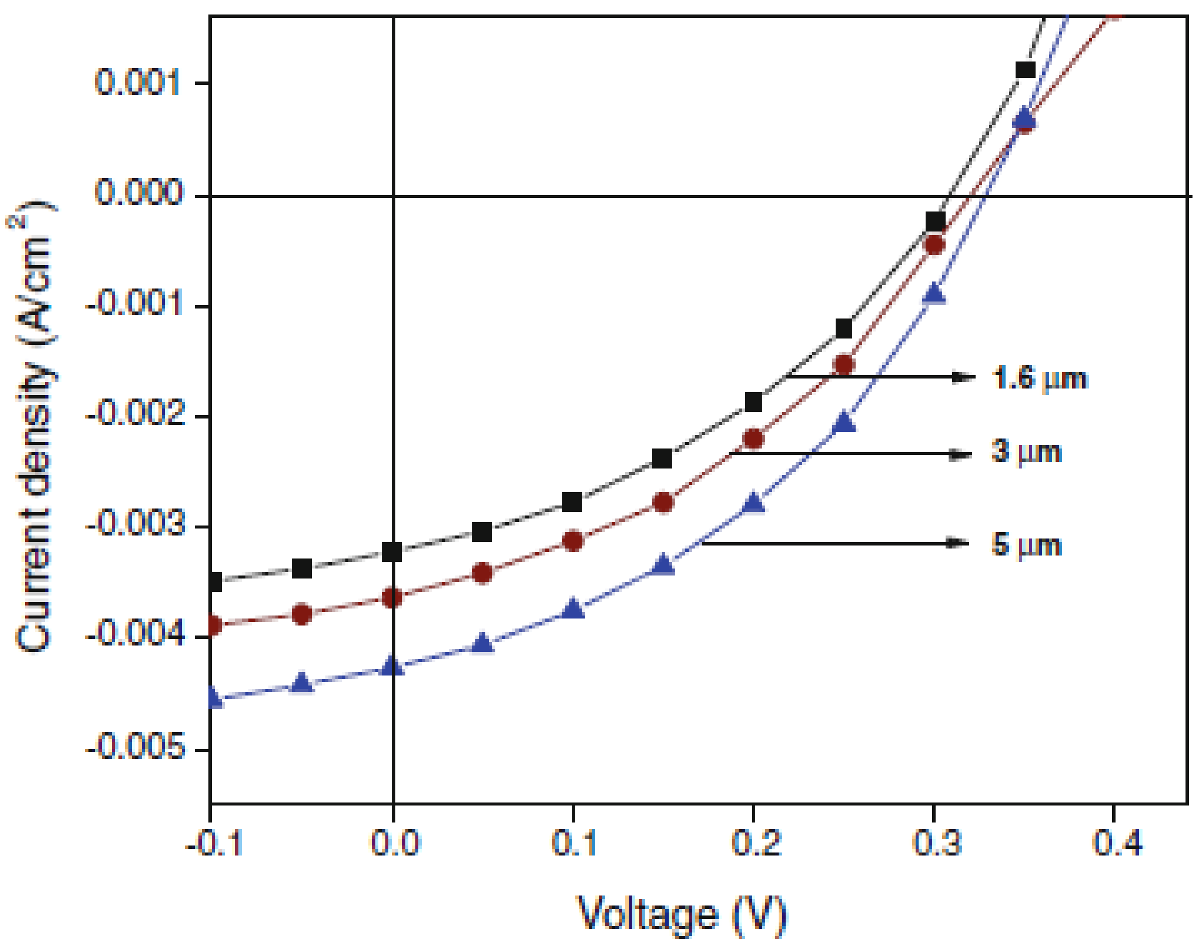
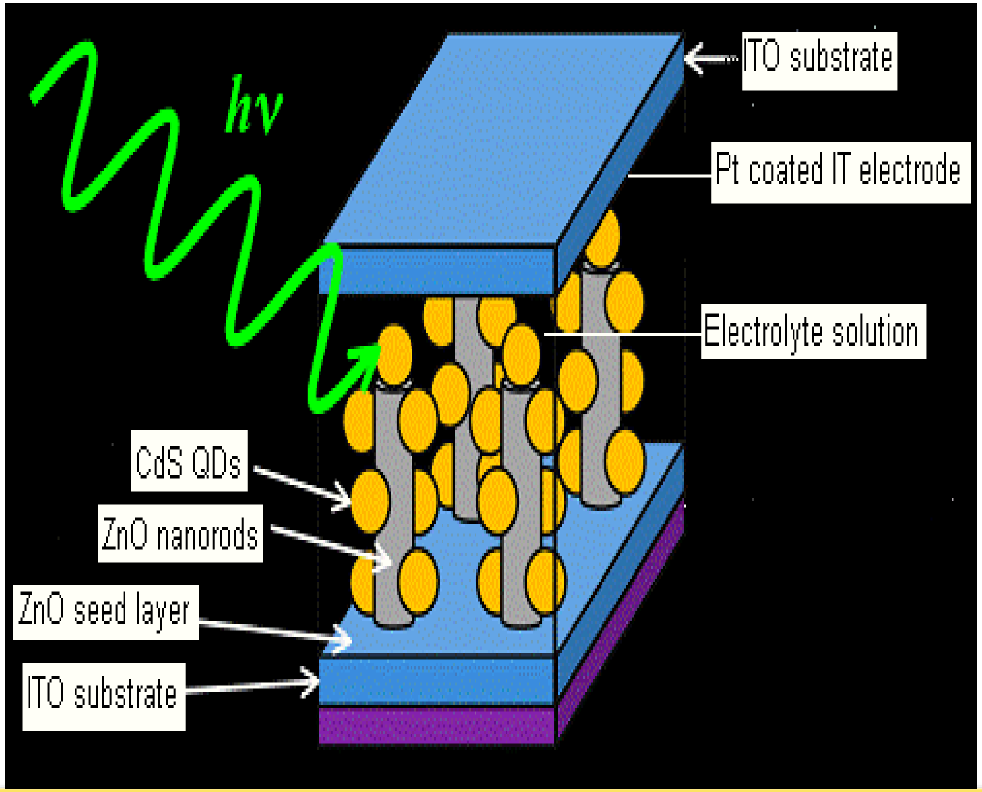


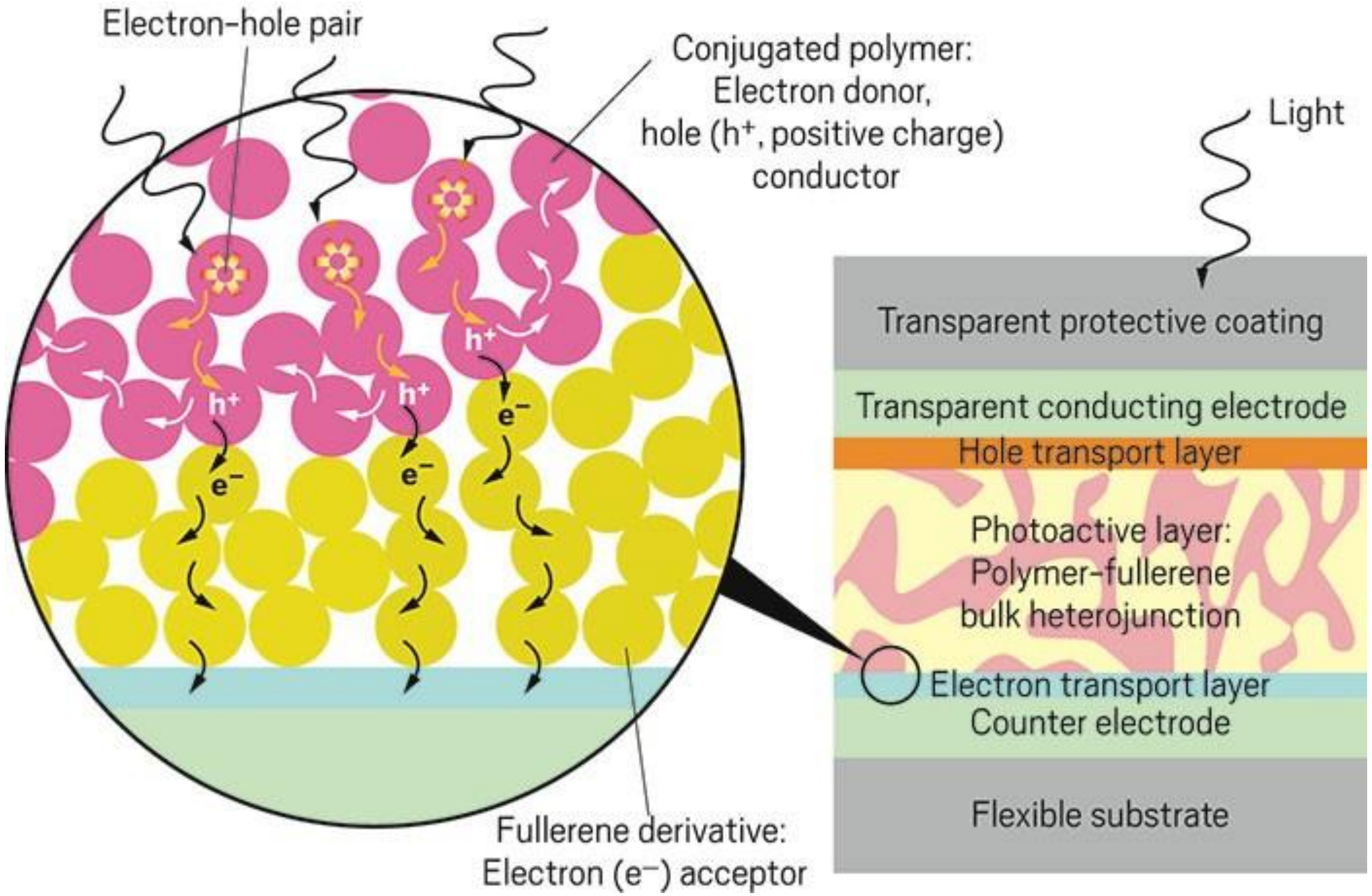
Fig. 7 J–V characteristics of CdS quantum dot sensitized ZnO nanorod based solar cells



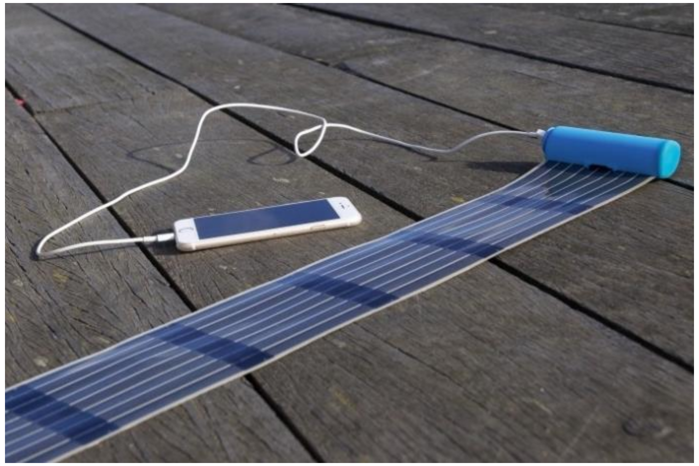
ZnO nanorods Thickness	Jsc (mA/cm^2)	Voc (V)	FF (%)	PCE (%)
1.6 µm	3.40	0.30	33	0.70
3.0 µm	3.63	0.31	39	0.87
5.0 µm	4.20	0.33	0.38	1.06

Organic solar cells

Maximum certified efficiency: 11.5%
Commercial status: advanced demonstration, some products for sale



Thanks to Chemical and Engineering News, Konarka Technologies

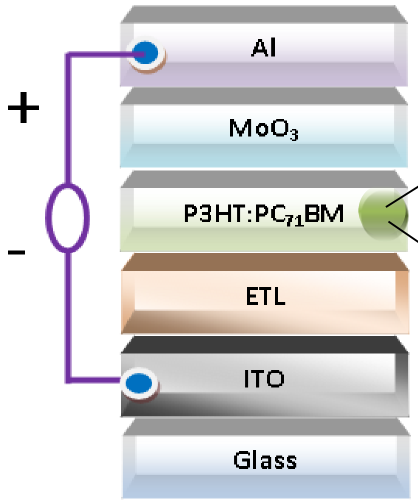


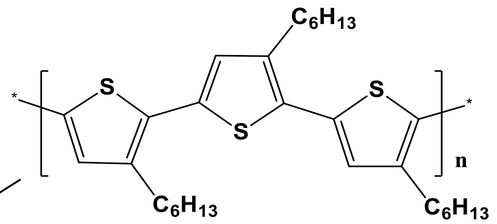
Thin, flexible organic photovoltaic panel and charges phone or battery indoors or out. Thanks: Infinity PV

Thin organic solar-cell panels can be integrated into cement and metal portions, not just glass, of a building facade. Thanks: Heliatek

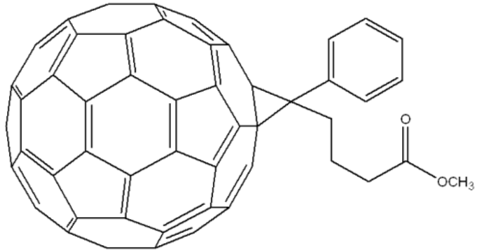
Inverted Organic Solar Cells

DEVICE STRUCTURE

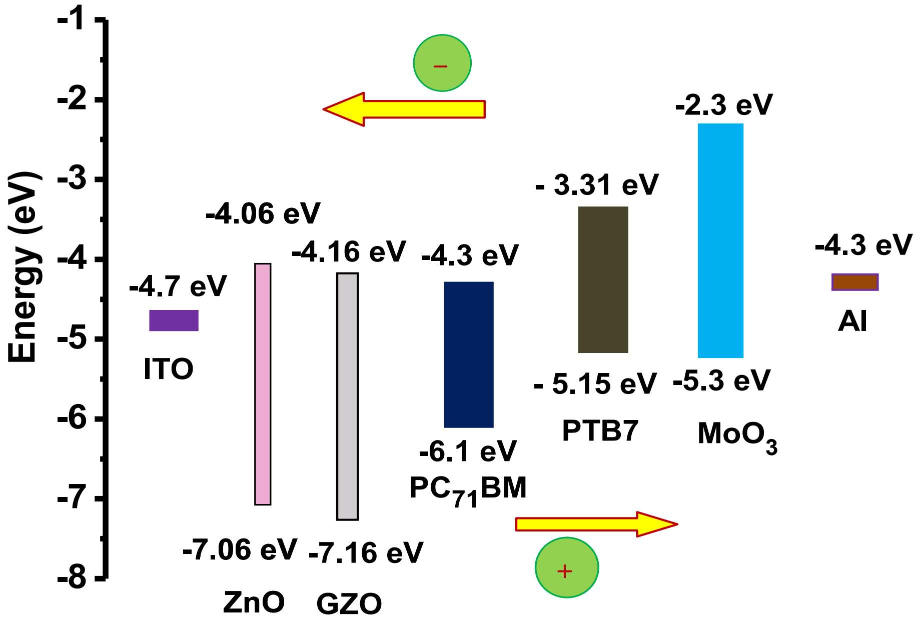




P3HT

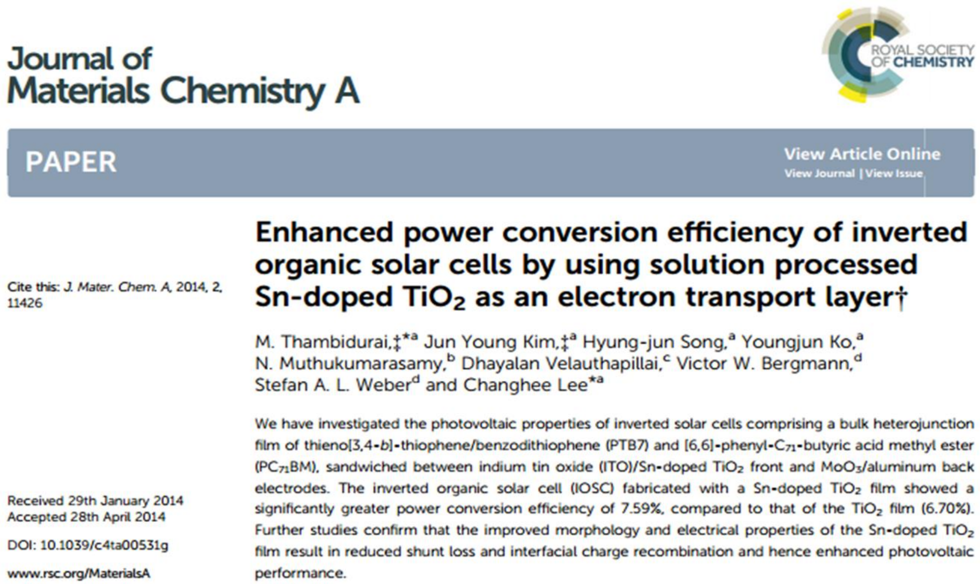


$PC_{71}BM$



Doped TiO_2 / PTB7:PC_{71}BM BASED INVERTED POLYMER SOLAR CELLS

Material	Jsc (mA/cm^2)	Voc (V)	FF (%)	PCE (%)
Al-doped TiO_2	15.26	0.76	65.69	7.66
Ga-doped TiO_2	15.48	0.77	64.86	7.72
In-doped TiO_2	15.45	0.76	65.06	7.67



Journal of Materials Chemistry A

PAPER

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Cite this: J. Mater. Chem. A, 2014, 2, 11426

Enhanced power conversion efficiency of inverted organic solar cells by using solution processed Sn-doped TiO_2 as an electron transport layer†

M. Thambidurai,‡*[a] Jun Young Kim,‡[a] Hyung-jun Song,[a] Youngjun Ko,[a] N. Muthukumarasamy,[b] Dhayalan Velauthapillai,[c] Victor W. Bergmann,[d] Stefan A. L. Weber[d] and Changhee Lee*[a]

We have investigated the photovoltaic properties of inverted solar cells comprising a bulk heterojunction film of thieno[3,4-b]-thiophene/benzodithiophene (PTB7) and [6,6]-phenyl-C_{71}-butyric acid methyl ester ($PC_{71}BM$), sandwiched between indium tin oxide (ITO)/Sn-doped TiO_2 front and MoO_3/aluminum back electrodes. The inverted organic solar cell (IOSC) fabricated with a Sn-doped TiO_2 film showed a significantly greater power conversion efficiency of 7.59%, compared to that of the TiO_2 film (6.70%). Further studies confirm that the improved morphology and electrical properties of the Sn-doped TiO_2 film result in reduced shunt loss and interfacial charge recombination and hence enhanced photovoltaic performance.

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www.rsc.org/MaterialsA

Nano

Nanoscale

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High-efficiency inverted organic solar cells with polyethylene oxide-modified Zn-doped TiO_2 as an interfacial electron transport layer†

Cite this: *Nanoscale*, 2014, **6**, 8585

Received 21st May 2014
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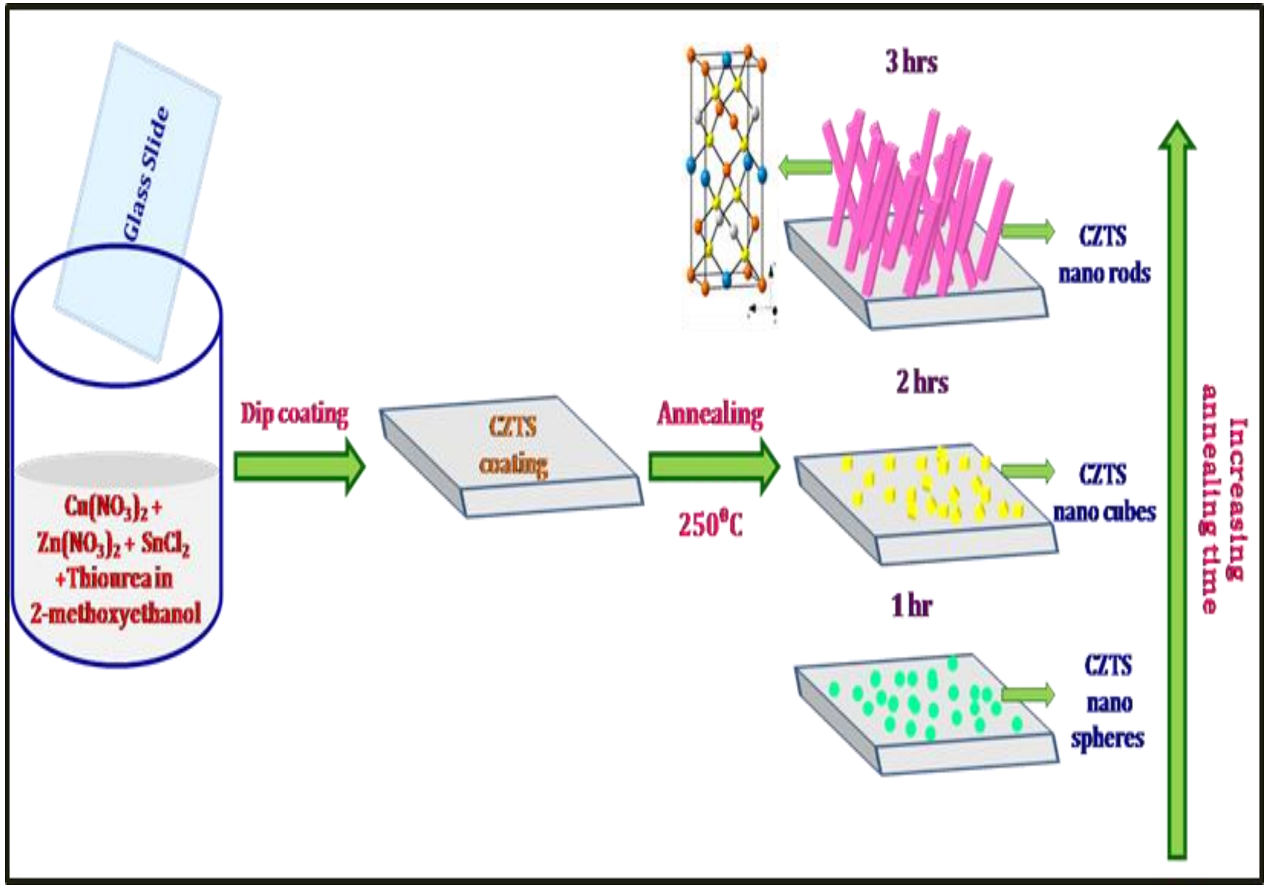
DOI: 10.1039/c4nr02780a

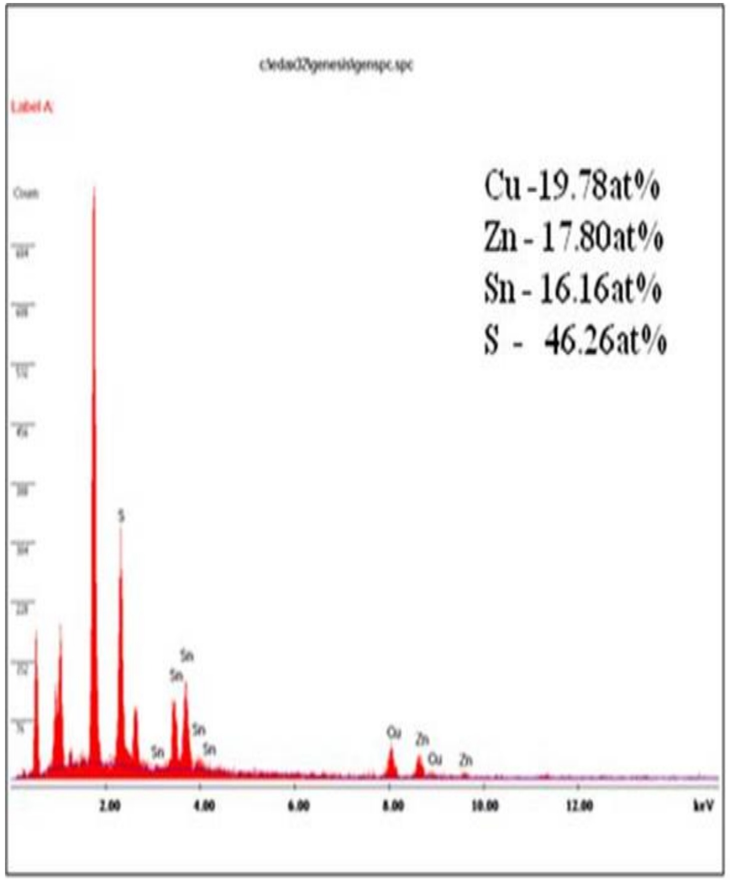
www.rsc.org/nanoscale

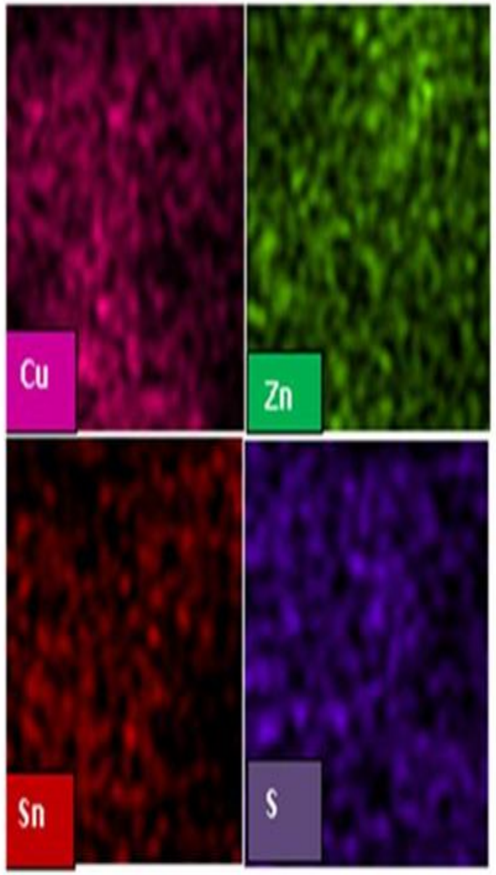
M. Thambidurai,‡*[a] Jun Young Kim,‡[a] Youngjun Ko,[a] Hyung-jun Song,[a] Hyeonwoo Shin,[a] Jiyun Song,[a] Yeonkyung Lee,[a] N. Muthukumarasamy,[b] Dhayalan Velauthapillai[c] and Changhee Lee*[a]

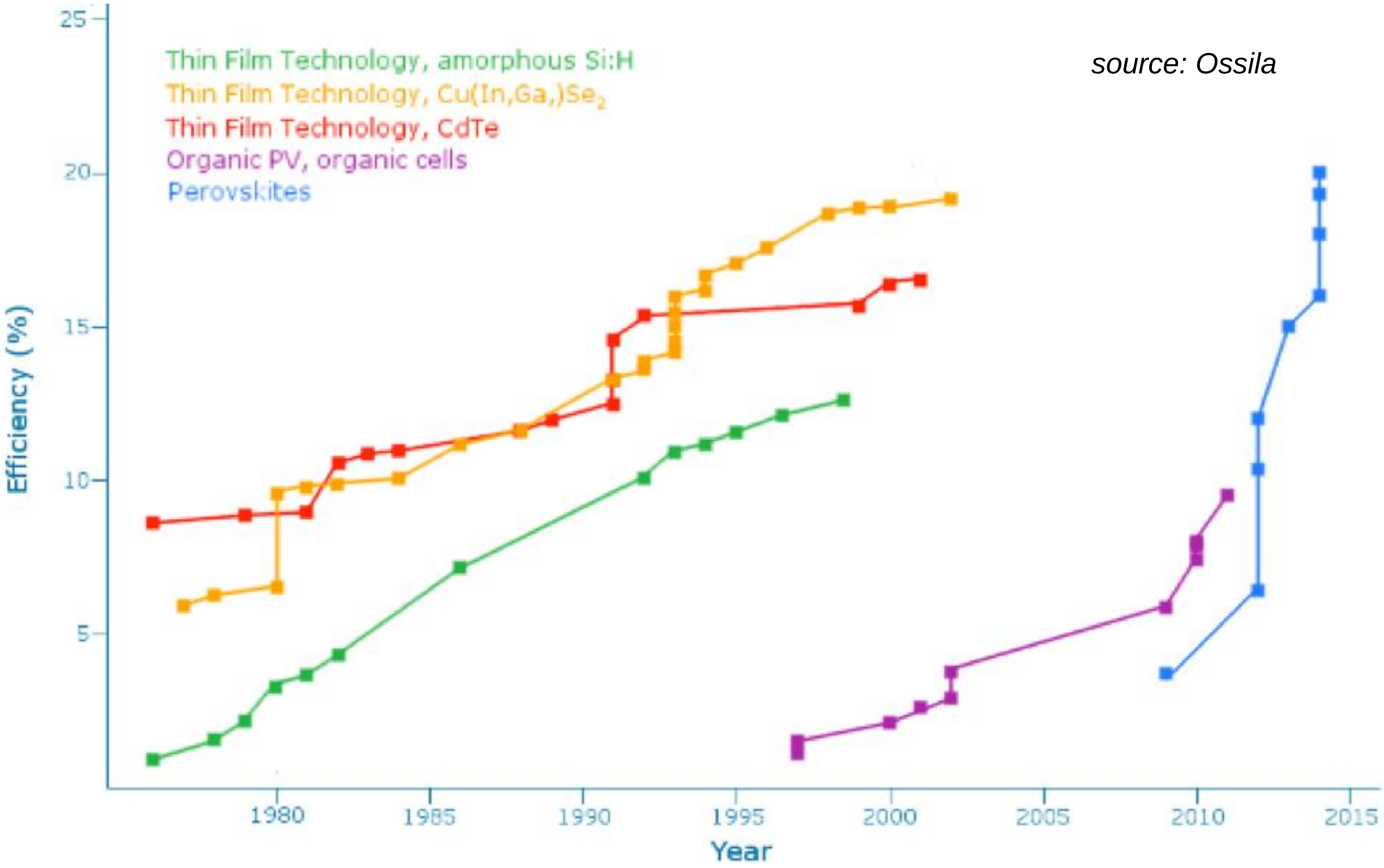
High efficiency inverted organic solar cells are fabricated using the PTB7:$PC_{71}BM$ polymer by incorporating Zn-doped TiO_2 (ZTO) and 0.05 wt% PEO:ZTO as interfacial electron transport layers. The 0.05 wt% PEO-modified ZTO device shows a significantly increased power conversion efficiency (PCE) of 8.10%, compared to that of the ZTO (7.67%) device.

CZTS Solar Cells (submitted in Feb 2017)





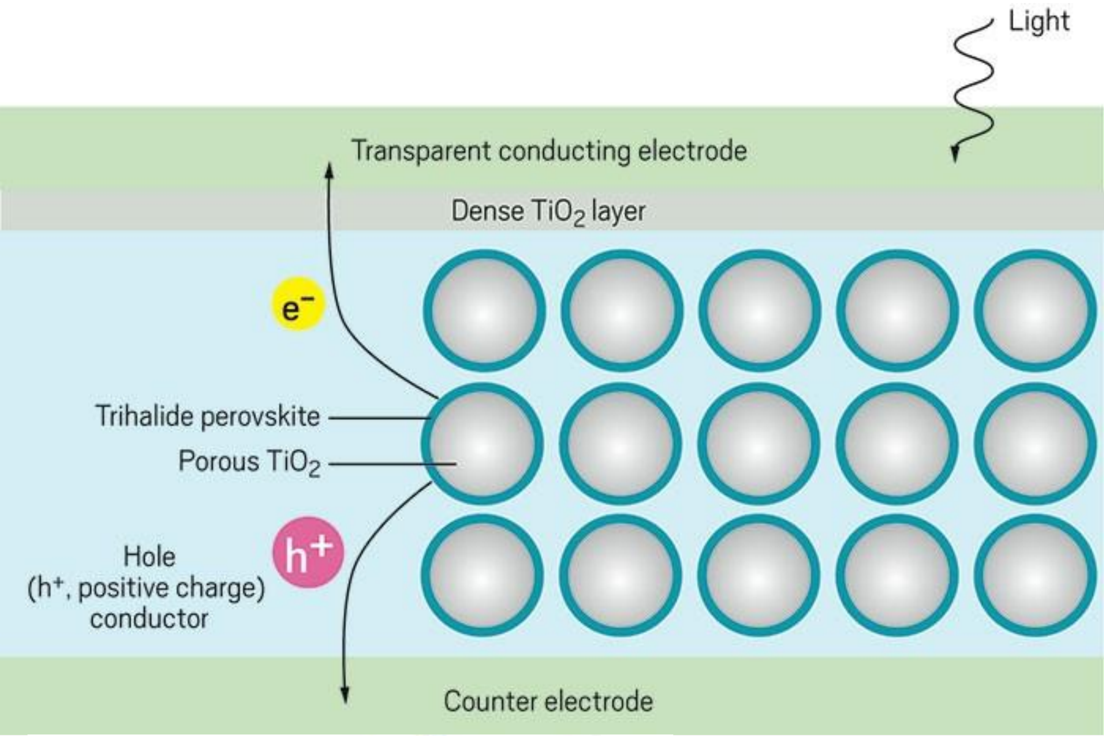


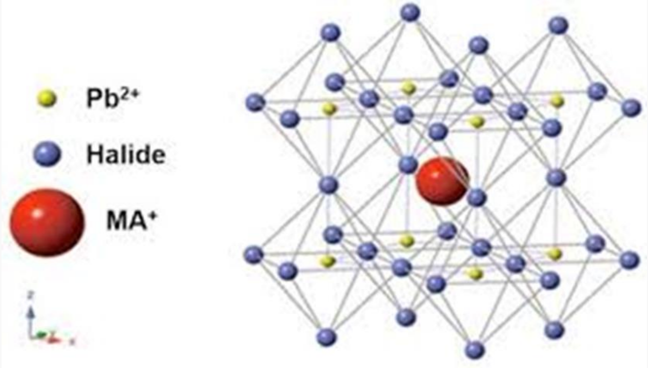

Thin Film Technology, amorphous Si:H
Thin Film Technology, Cu(In,Ga,)Se2
Thin Film Technology, CdTe
Organic PV, organic cells
Perovskites
source: Ossila
Efficiency (%)
25
20
15
10
5
1980
1985
1990
1995
2000
2005
2010
2015
Year

Perovskite solar cells

Maximum certified efficiency: 22.1%

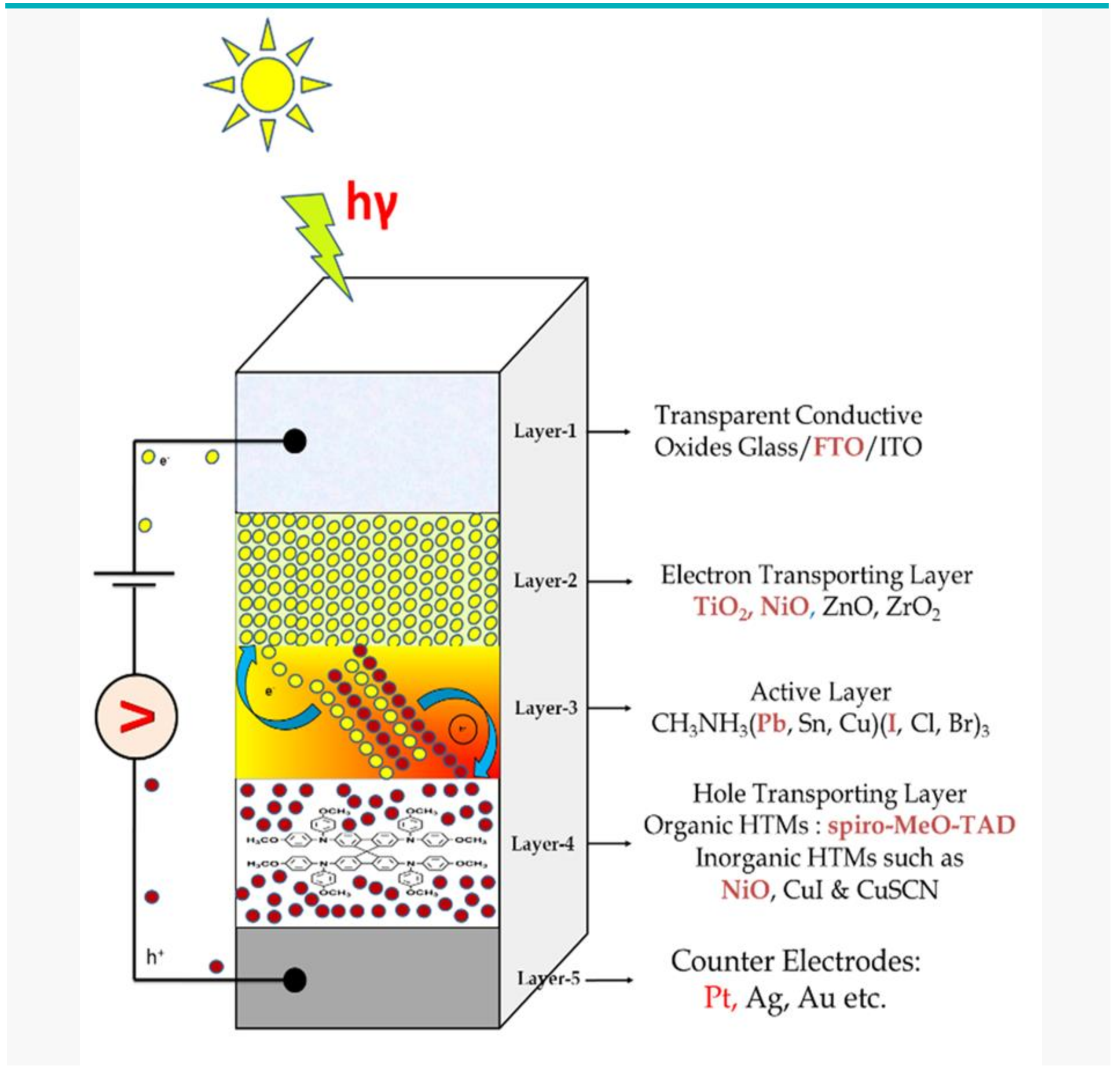
Commercial status: development, no products





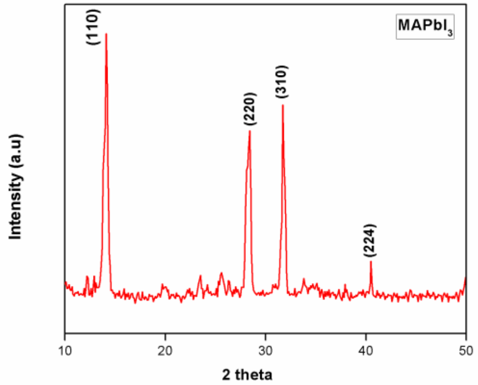
Credit: J. Phys. Chem. Lett.

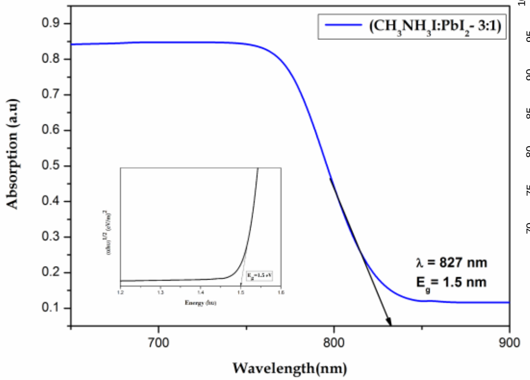
Methyl Ammonium Lead Iodide Perovskite ($CH_3NH_3PbI_3$)

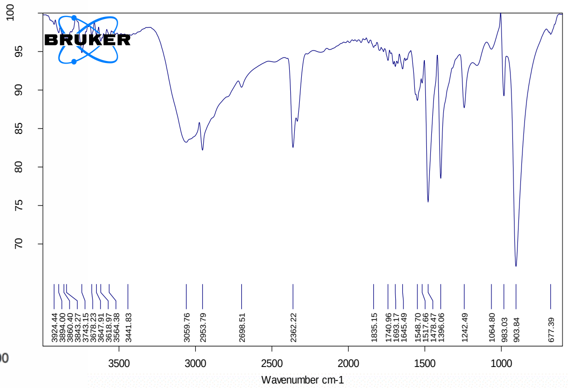


PEROVSKITES – CHARACTERIZATIONS

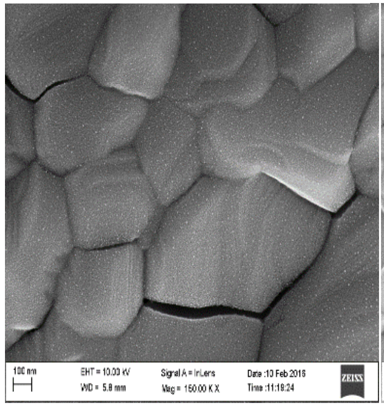
XRD
UV
FTIR

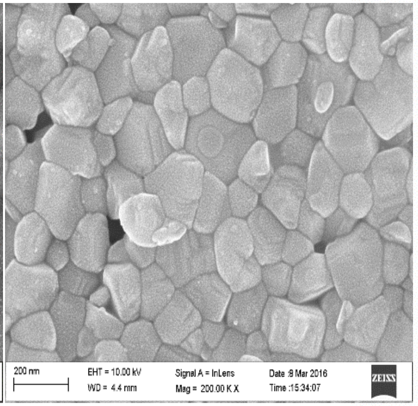


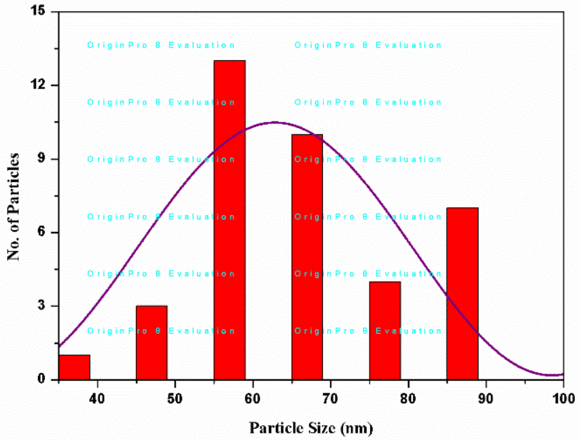




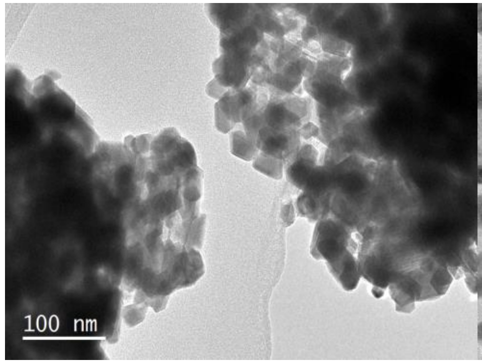
SEM IMAGES
PARTICLE SIZE

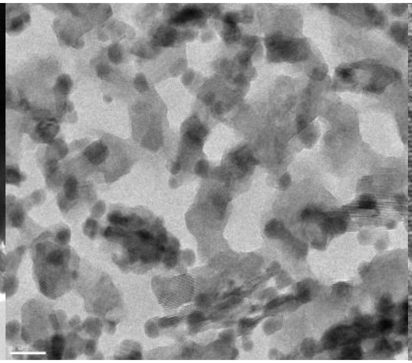


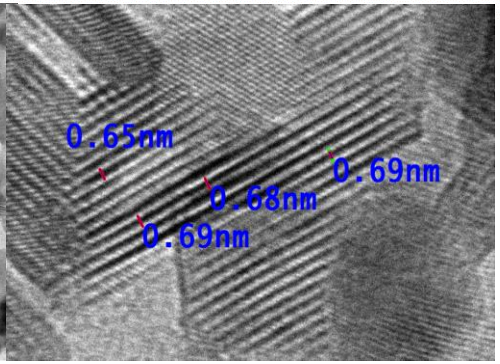




HRTEM IMAGES







Solar Paint – in future ???

nanoflexpower.com

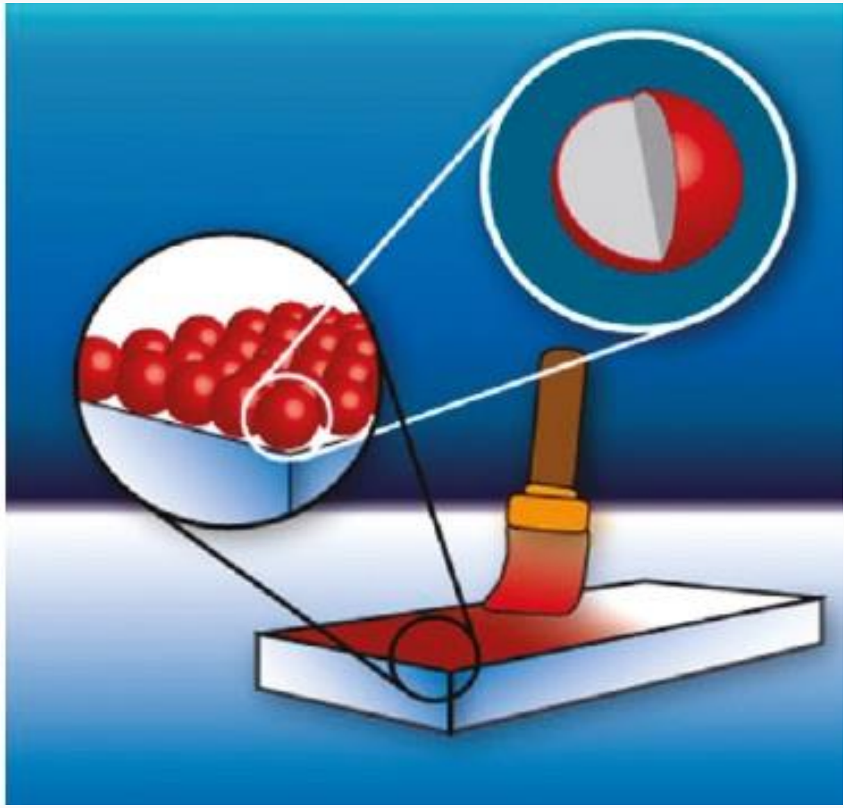
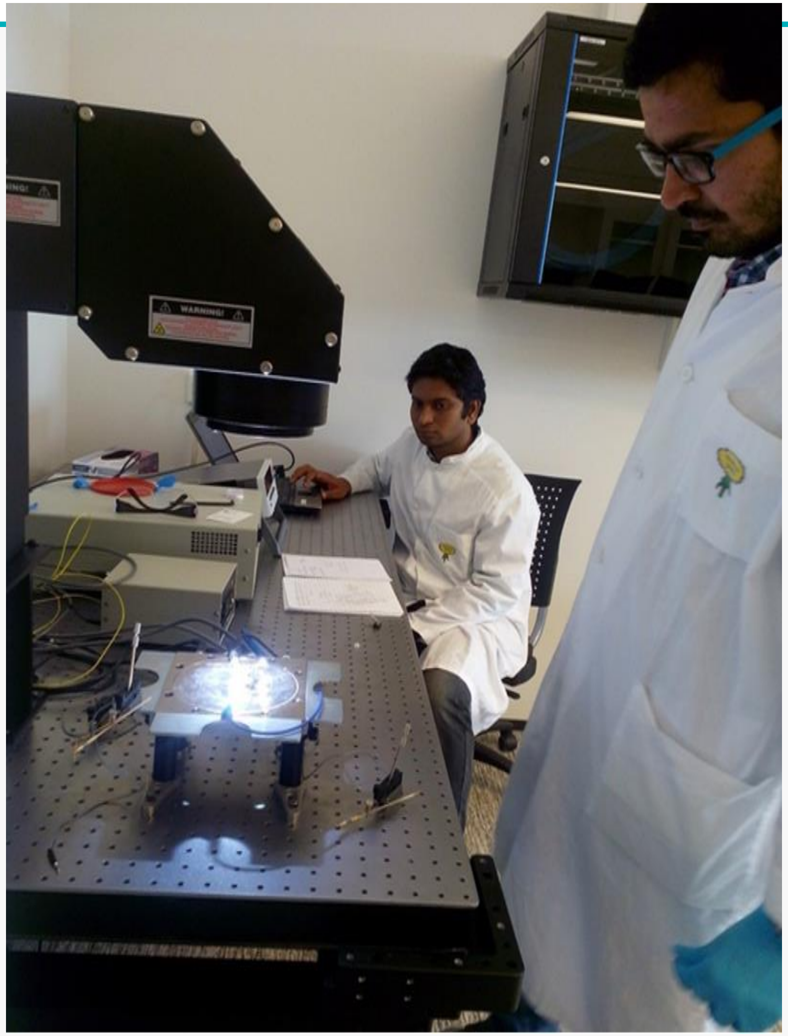


Image credit: Mathew P. Genovese, et al.

Facilities at HiB (Chemistry and Electronic Labs)

Synthesizing nano materials

- Microwave method
- Chemical method
- Sol-Gel method
- Dip Coating facilities
- Spin Coating facilities



Solar simulator and IV characterization system for solar cells

Advanced Nano materials for Clean Energy Applications (ANCEA)